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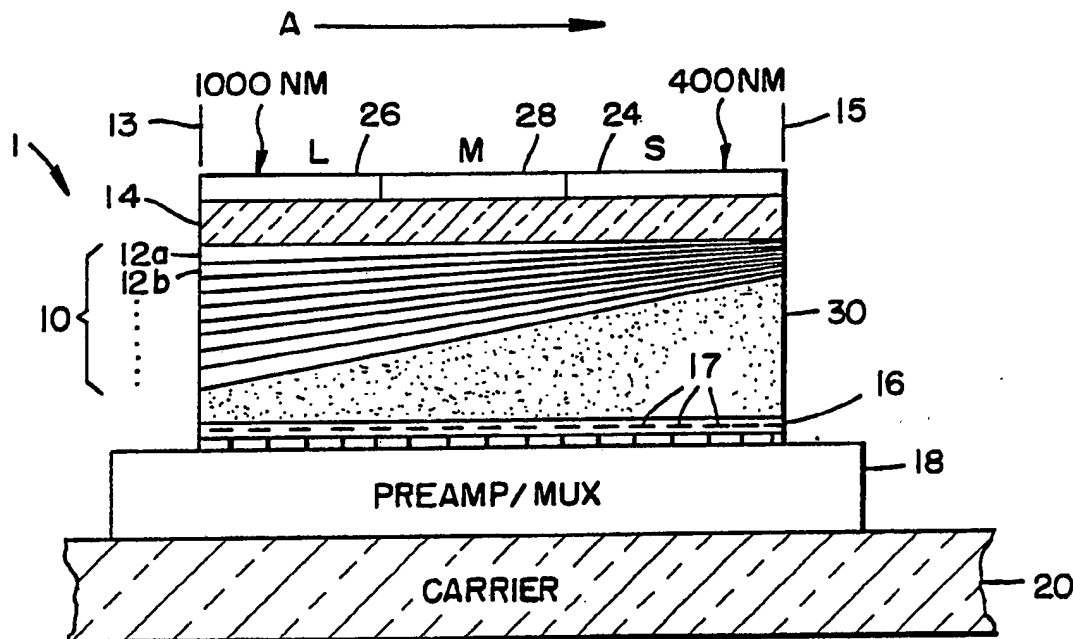
(57) Abstract

A wedge-filter spectrometer (1) comprises means (10) for spectrally dispersing an incident radiation beam comprising a first plurality of layers of high (H) index of refraction material and a second plurality of layers of low (L) index of refraction material, individual ones of the H and the L layers overlying one another in accordance with a given sequence, each of the H and the L layers having a substantially linearly tapered thickness of substantially constant slope, and means for detecting (17) at a plurality of points a spectrally dispersed radiation beam, the radiation beam being spectrally dispersed by the H and the L layers.

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1   WEDGE-FILTER SPECTROMETER

                   FIELD OF THE INVENTION

5   The present invention relates to spectrometers and, in
         particular, relates to a wedge-filter spectrometer
         having a compact wedge-shaped spectral disperser
         optically coupled to an electro-optical detector and
         also relates to apparatus and methods of fabricating a
10   wedge-shaped spectral disperser.

                  BACKGROUND OF THE INVENTION

         Spectrometers having either a prism or a grating as a
15   spectral dispersing element are known. Both prism and
         grating spectrometers require that relay optics be
         provided within the system. The inclusion of such relay
         optics has an adverse effect on the size and on the
         mass and stability of the system. In general, the
20   spectral stability and accuracy of such systems are
         compromised by the mechanical sensitivity of the prism
         or grating and associated relay optics. Such an
         adverse effect on system size, mass and stability is
         particularly   disadvantageous   for   portable
25   spectrometers, such as spectrometers intended for
         mobile and spaceborne applications. In such portable
         applications the vibration and motion of a platform, in
         conjunction with the large size and mass of the
         spectrometer, may render the spectrometer unusable for
30   its intended purpose.

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1   Another type of spectrometer is an interferometer. The
        use of conventional interferometers is also attended by
        several problems. In general, these problems with
        known interferometers are characterized as including
5   precision moving parts, non-simultaneous wavelength
        acquisition and severe signal processing constraints.

        In U.S. Patent No. 3,442,572 Illsley et al. disclose a
        wedged filter which is deposited in a circular path
10   around a substrate having a diameter of 6.4 centimeters
        by the use of two rotating sector masks or by a
        rotating substrate and a rotating mask in conjunction
        with a stationary sector mask. The rotating elements
        have a 2:1 angular velocity ratio. This wedged filter
15   is relatively large, its circular shape may be
        unsuitable for many applications and the required
        tooling to fabricate the filter is complex.

        It is thus one object of the invention to provide for a
20   wedge filter having a simplification of manufacturing
        tooling.

        It is a further object of the invention to provide a
        wedge filter having a linear wedge.
25
        It is a further object of the invention to provide a
        linear wedge filter of small size and mass.

        It is still one further object of the invention to
30   provide a wedge filter which may be advantageously
        integrated with an orthogonally patterned detector
        array.

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SUMMARY OF THE INVENTION

The foregoing problems are overcome and the objects are realized by a wedge-filter spectrometer constructed in accordance with a method and apparatus of the invention wherein a wedge-filter spectrometer comprises means for spectrally dispersing an incident radiation beam comprising a first plurality of layers of high (H) index of refraction material and a second plurality of layers of low (L) index of refraction material, individual ones of the H and the L layers overlying one another in accordance with a given sequence, each of the H and the L layers having a substantially linearly tapered thickness of substantially constant slope, and means for detecting, at a plurality of points, a spectrally dispersed radiation beam, the radiation beam spectrally dispersed by the H and the L layers.

There is also disclosed a method of depositing a layer of material upon front surface of a substrate such that the layer has a predetermined linearly tapered thickness along a given axis of the substrate and a substantially constant slope. The method comprises the steps of providing a substantially transparent substrate upon a substrate mount, translating the substrate mount in an oscillatory linear manner along an axis coincident with the given axis, directing a flow of material to the front surface of the substrate in a direction normal to the given axis, the flow depositing a layer of the material upon the front surface. The method further comprises a step of positioning an aperture within the flow such that the aperture selectively blocks the flow from reaching the

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1   front surface of the substrate as .the substrate is
     translated past an edge of the aperture, the substrate
     thereby being translated into and out of the flow such
     that a linearly tapered thickness of material is
5   deposited on the front surface. The method further
     comprises the steps of passing a first and a second
     beam of radiation through a back surface of the
     substrate at a first and a second predetermined point,
     respectively, relative to a reference point; detecting
10   the magnitude of the intensity of the first and second
     beams of radiation after they have passed through the
     substrate and through the layer and comparing the
     detected intensity of each of the beams to a reference
     intensity to determine a difference therebetween, the
15   difference of the intensity of each of the beams from
     the reference intensity being indicative of the
     thickness of the layer at' the first and the second
     predetermined points.

20   BRIEF DESCRIPTION OF THE DRAWINGS

     The foregoing aspects of the method and apparatus of
     the invention will be made more apparent in the
     detailed description of the invention taken in
25   conjunction with the accompanying drawings wherein:

     Fig. 1 is a side view of a linear wedge-filter spectral
     disperser integrally joined to a two dimensional
     photodiode detector array;

30
     Fig. 2 is a graph which shows the radiation
     transmission passbands of a device constructed in
     accordance with the method and apparatus of the

5

1   invention, the device not including out-of-band
       blocking layers;

       Fig. 3 is a block diagram of linear wedge-filter
5   fabrication apparatus suitable for accomplishing a
       method of the invention; and

       Fig. 4 shows in more detail a portion of the apparatus
       of Fig. 3.

10
                DETAILED DESCRIPTION OF THE INVENTION

       Referring now to Fig. 1 there is shown a side view of
       an illustrative embodiment of a wedge-filter
15   spectrometer 1 constructed in accordance with the
       method and apparatus of the invention. Spectrometer 1
       is comprised of a continuous spectral disperser 10
       which is constructed of alternating high refractive
       index and low refractive index dielectric layers (12a,
20   12b, etc.) whose thicknesses are tapered in a
       controlled manner from a first edge 13 of a
       substantially transparent substrate 14 to an opposing
       second edge 15 of the substrate 14. The layers 12 are
       deposited upon the substrate 14 in a manner which will
25   be described below. Substrate 14 is fabricated from
       material selected to be essentially transparent to
       radiation in the spectral regime of interest, e.g., it
       may be comprised of optical glass for transmitting
       visible radiation or of silicon for near-infrared
30   radiation (IR). An impinging radiation cone is
       typically oriented at some angle of between, for
       example, 10° to 20° from a surface normal of substrate
       14.

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The layers 12 are comprised of high (H) refractive index and low (L) refractive index dielectric layers deposited one upon another in accordance with the sequence

H LL HLHLHL HH LHLHLH LL HL

and which are graded in thickness such that each of the layers has a constant slope. The layers 12 constitute an interference filter which isolates a transmission passband of wavelength equal to 4nt, where n is the value of either the high refractive index or the low refractive index material and t is the physical thickness of a layer of corresponding index of refraction material at a particular point along the spectral disperser 10 from a reference position, such as the first edge 13. The spectral disperser 10 constructed as described above may be integrated with a two dimensional array 16 of detector elements 17 to produce a unitary spectrometer device of small physical size and mass operable for discriminating passband wavelengths according to specific detector element 17 locations within the array 16. The detector elements may be arranged in an orthogonal two dimensional array of detector elements characterized in a well known manner by rows and columns of detector elements. At any particular position along the tapered direction, indicated by the arrow A, a wavelength passband profile is resolved the bandwidth of which is proportional to the detector element 17 size and to the center wavelength of the passband. Such an integrated construction overcomes many of the problems of conventional spectrometers in that it eliminates a

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requirement for relay optics and thus achieves a
minimum size and a mechanical ruggedness which may be
utilized with either parallel or focussed radiation and
which also beneficially provides continuous spectral
coverage over a wide range of wavelengths. For
example, the spectrometer 1 may be substantially cubic
in shape having edges of approximately 1 cm in length.

Also shown in Fig. 1 is an integrated circuit
preamplifier/multiplexer 18 which may also be
integrated with the spectrometer, the preamplifier and
multiplexer 18 being coupled to individual ones of the
detector elements 17 in a well known manner for
selectively amplifying output signals of the detector
elements 17. The preamplifier/multiplexer 18 may be
further mounted on a suitable carrier 20 which provides
mechanical support and electrical isolation for the
spectrometer 1.

In the sequence of dielectric layers 12 H represents a
layer comprised of a high refractive index material
having an optical thickness substantially equal to one
fourth of a reference wavelength λ_0. L represents a
layer 12 comprised of a low index of refraction
material also having a thickness substantially equal to
one fourth of the reference wavelength λ_0. The
reference wavelength, λ_0, may be derived from the
equation

$$\lambda_0 = 4n_H t_H = 4n_L t_L, \qquad (1)$$

wherein the subscripts refer to the H or L index of
refraction material. As can be realized from equation

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1   1, if the thickness of a layer is varied a passband
       center wavelength, λ_c, will also vary. Thus, by
       tapering the layer thicknesses along the length of the
       substrate 14 the wavelength of interference will be
5   different for all positions along the length. Also, by
       depositing the layers such that the thickness of the
       layers has a constant slope, the wavelength of the
       passband will also vary continuously.

10   As an example, the sequence of layers given above
       constitutes a multiple-order interference filter which
       isolates a wavelength passband having a width equal to
       approximately two percent of λ_c at the half
       transmittance points of the filter. The ratio of the
15   refractive indices H/L and the order of the filter
       substantially determine the value of the half
       bandwidth. The order of the filter is given, in
       general, by the number of adjacent quarter-wave layers
       disposed within a resonant cavity structure. Thus, a
20   sequence of layers 12 given by

                HL HL HL [HH] LH LH LH

       defines a resonant cavity having a passband centered
25   upon a wavelength of $\lambda_c = 2\lambda_0$, the passband having a
       width determined by the number of wavelengths which
       will evenly fit within a spacer layer denoted by the
       layers within the square brackets []. As the thickness
       of the spacer layer is increased, the bandwidth
30   decreases in an inverse ratio. Furthermore, as more
       such resonant cavities are overlaid one upon another in
       a series fashion, the edges of the passbands become
       steeper and the energy at wav lengths removed from λ_c

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1   is rejected by reflection to an increasing degree.
      Thus, the out-of-band transmission is attenuated to the
      level where the passband transmission is a virtually
      pure transmission. The wavelength region over which
5   such rejection occurs is given by a relationship
      between the values of high and low refractive indices
      and is expressed as a fraction of wavelengths. This
      relationship is given by the equation

$$\Delta\lambda_0 / \Delta\lambda_c = 4/\pi \; \sin^{-1} (n_H - n_L / n_H + n_L). \quad (2)$$

10

      Higher order passbands are found to occur at even
      multiples of the spacer layer thickness. These higher
      order passbands are separated by rejection regions
15   located at odd multiples of λ_0.

      It has been observed that there may be an undesired
      energy component appearing at wavelengths removed from
      the λ_c of interest. It has also been observed that
20   this undesired energy may be prevented from reaching
      the detector 16 by the addition of interference filter
      blocking stacks 22.

      As an example, to provide a spectrometer 1 for
25   operation over the visible/near IR region, that is the
      region characterized by wavelengths from 400 to 1000
      nm, three blocking filter stacks may be deposited on
      the opposite face of the transparent substrate 14 from
      the tapered layers 12. In region S, a filter stack 24
30   is provided, the stack 24 rejecting substantially all
      energy of wavelengths greater than 532 nm while
      transmitting efficiently wavelengths below 520 nm. In
      region L, a filter stack 26 is provided which transmits

1   efficiently substantially all wavelengths above 770 nm
         while substantially reflecting all wavelengths below
         760 nm. Stacks 24 and 26 may be comprised of constant
         thickness quarter wave layers. In the middle region,
5   region M, a wide bandpass stack 28 having, in
         accordance with the invention, tapered layers is
         deposited to provide wide range blocking for the
         passbands originating from the middle region of the
         filter 12.
10 .

         The stacks 24 - 28 may be characterized as follows:

         stack 24, transmissive to wavelengths < 520 nm, has
         layers $[LH]^6$ 1.6 $[LH]^6$, where L and H are quarter waves
15   at λ = 250 nm;

         stack 28, transmissive to wavelengths of 530 nm < λ <
         760 nm, has layers $[LH]^7$ 2 $[LH]^7$, where L and H are
         quarter waves at λ = 420 nm; and
20

         stack 26, transmissive to wavelengths of λ > 770 nm,
         has layers $[LH]^6$ 1.3 $[LH]^6$, where L and H are quarter
         waves at λ = 520 nm.

25   The spectral disperser 10 as described above may be,
         after fabrication, coupled to an underlying integrated
         detector, which includes the two dimensional photodiode
         array 16 and the preamp/multiplexer 18, such as by
         bonding the spectral disperser 10 with an epoxy or
30   optical cement 30. As can be seen, the cement 30 is
         applied such that it has a corresponding wedged shape
         such that the substrate 14 is aligned in a
         substantially parallel manner with the array 16 of

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detectors 17. Such a structure as shown in Fig. 1
achieves, with minimal spacing between detectors 17, a
significant   reduction   in   detector-to-detector
crosstalk, this reduction in optical crosstalk being
advantageous in a focal plane type of application.

Although   the   above   described   embodiment   of   the
invention discloses the use of a solid-state, two
dimensional detector array, the spectral disperser 12
which forms a part of the invention may be utilized
with   a   variety   of   different   types   of   detectors,
including   vidicons,   photomultipliers   having
microchannel   plates,   CCD   imagers,   and   other   such
photodetecting devices.   Also, the use of the wedged
spectral disperser of the invention is applicable over
a broad range of the electromagnetic spectrum from at
least the ultra violet through the longwave infrared.
It should also be realized that in some applications it
may be desirable to eliminate the transparent substrate
14 and deposit the tapered layers directly onto, for
example,   the   detector   array   or   upon   a   vidicon
faceplate.   This achieves a still further reduction in
system mass inasmuch as the detector array or vidicon
faceplate functions in an analogous manner to the
substrate 14.

The graph of Fig. 2 shows the spectral response of a
spectrometer, constructed in accordance with the method
and apparatus of the invention, for a range of incident
wavelengths of between approximately 850 to 1100 nm.
The graph of Fig. 2 can be seen to show well defined
transmission passbands.   It should b noted that the
graph of Fig. 2 is illustrative of data obtained from a

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1   spectral disperser not having the out-of-band blocking
     stacks 24-28 deposited thereon.

     Referring now to Figs. 3 and 4 there is shown apparatus
5   operable for realizing a method of the invention of
     producing the tapered layers 12 having a constant
     slope. In general, in order to deposit the layers 12
     such that each has a thickness which varies in a
     constant manner from the first edge 13 of the substrate
10   14 to the opposing edge 15 the substrate 14 is driven
     at a substantially constant speed as it is exposed from
     behind a knife-edge aperture, in a oscillatory manner,
     to an evaporant stream of either H or L material. The
     knife-edge aperture placed adjacent to the substrate 14
15   produces a sharply defined evaporant stream deposition
     front. The substrate is held on a precision
     translation stage which is driven by a constant speed
     motor having a position encoder and a feedback control.
     The operation of the motor exposes the substrate to the
20   evaporant stream. The position encoder tracks the
     linear displacement of the stage to a precision of
     approximately 2 microns. The thickness of a growing
     layer is monitored in a real time manner at two
     positions along the wedge dimension with two different
25   wavelengths from a laser source. For example, a Nd:YAG
     continuous duty laser having a frequency doubling
     crystal is located outside of a vacuum chamber wherein
     the layers are deposited. A dichroic beam splitter
     physically separates the two wavelengths from the
30   doubling crystal and directs each of the wavelengths to
     the vacuum chamber where they pass through the
     substrate 14 at precisely known distances from a
     reference edge, such as the edge 13, of the substrate.

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1   Such an optical method of monitoring the growth of the
        layer accomplishes at least three valuable features
        simultaneously. Firstly, the quarter wave thicknesses
        of the layers are continuously and accurately monitored
5   such that the stopping point of layer growth for each
        layer is precisely determined. Secondly, inasmuch as
        the locations of the passband centers for the two laser
        wavelengths are fixed, an automatic self-calibration of
        wavelength versus distance along the wedge direction is
10   accomplished. Thirdly, the linearity of the layer
        slope is measured by the two known wavelengths
        transiting the tapered wedge coating at precisely
        known points along the wedge direction.

15   As can be seen in Figs. 3 and 4, a tapered layer
        deposition system 40 as generally described above is
        comprised of a vacuum deposition chamber 42 wherein a
        substrate mount 44 has a substrate 46 affixed thereon.
        Substrate 46 is the transparent substrate upon which
20   the layers are to be deposited, such as the substrate
        14 of Fig. 1. As previously stated the substrate 46
        may comprise, for example, a radiation detecting array
        or a vidicon faceplate. Not shown in Fig. 3 is a
        vacuum generation means for evacuating the chamber 42.
25   Also not shown is the constant speed motor, position
        encoder and feedback control which drive the substrate
        mount 44 in a linear oscillatory manner as shown by the
        arrow A. An electron beam source 48 is positioned
        within the chamber 42 for directing an evaporated
30   stream of H or L material which is to be deposited on
        the substrate 46. The knife-edge aperture 49 provides
        for the sharply defined deposition front. For example,
        the L layers may be comprised of silicon dioxide. The

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1   H layers may be comprised of titanium dioxide. These
     materials have been found to be suitable for use with
     wavelengths corresponding to visible radiation. A
     frequency doubled Nd:YAG laser 50 has an output beam 51
5   of wavelengths of 532 nm and 1064 nm, the output beam
     51 being directed through a chopper 52 to a dichroic
     beam splitter 54 which is operable for separating the
     two wavelengths of the beam 51. The separated
     wavelengths form two distinct beams which travel
10   substantially parallel one to another as shown by the
     beams B and C. The two beams B and C are directed such
     that they pass through the transparent substrate 46 at
     precisely determined points from a reference point and
     are thereafter reflected by a mirror 56 out of the
15   chamber 42. Positioned adjacent to a window 58 may be
     a reflector 60 for reflecting the ray C to a first
     detector 62. The ray B is incident upon a second
     detector 64.

20   In accordance with the method of the invention, the
     beams from the YAG laser 50, having two precisely known
     wavelengths, are directed through the transparent
     substrate upon which the layers are being deposited.
     Each of the beams is thereby modified in intensity in
25   accordance with the thickness of the layer. The
     intensity of each of the beams is detected by a
     separate detector, such as by a photodiode coupled to
     an amplifier. The output of the amplifier is
     indicative of the beam intensity and is thus also
30   indicative of the layer thickness at the point where
     the beam intersects the layer. Also shown in Fig. 3 is
     a reference detector channel 66 which monitors the
     output of the laser 50 and which is used to normalize

15

1   the beams B and C which are detected by detectors 62
    and 64. Thus, any intensity fluctuations which may be
    present in the output of the laser are not interpreted
    as changes in deposited layer thickness.

5

    A controller 68 may be provided for receiving the
    outputs of the reference channel 66 and the detectors
    62 and 64 for determining the thickness and slope of
    the layers. Controller 68 may include a data
10 processing means, such as a microcomputer operable for
    reading the intensity values and calculating the layer
    thickness and slope from the intensity values.
    Controller 68 may also be operable for controlling the
    E-beam source to switch between L and H evaporant
15 material at appropriate times.

    The method advantageously provides for a continuous
    determination of the layer thickness at two points
    along the desired taper direction, thereby enabling the
20 E-beam source to be alternatively switched between H
    and L material when a layer is deposited to a desired
    quarter wave thickness. Also, the linearity of the
    slope of the layer may be simultaneous determined
    inasmuch as the measured beam intensities will differ
25 one from the other by an amount related to the
    difference in thickness of the layer along the taper
    direction.

    It should be realized that the method and apparatus of
30 the invention disclosed above is illustrative only, and
    that based on the foregoing teaching, modifications
    thereto may occur to those having skill in the art.
    Thus, the method and apparatus of the invention is not

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1   to be limited by the embodiments disclosed herein, the
        invention is instead meant to be limited only as
        defined by the scope of the appended claims.

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CLAIMS

What is claimed is:

1   1.   A wedge-filter spectrometer comprising:

          means for spectrally dispersing an
          incident radiation beam comprising a
          first plurality of layers of high (H)
5   index of refraction material and a
          second plurality of layers of low (L)
          index of refraction material, individual
          ones of said H and said L layers
          overlying one another in a given
10·   sequence, each of said H and said L
          layers having a substantially linearly
          tapered thickness of substantially
          constant slope; and

          means for detecting at a plurality of
15   points a spectrally dispersed radiation
          beam, said radiation beam being
          spectrally dispersed by said H and said
          L layers.

1   2.   A spectrometer as defined in Claim 1
     wherein said given sequence is

          H LL HLHLHL HH LHLHLH LL HL.

          3.   A spectrometer as defined in Claim 2
5   wherein said layers isolate a radiation transmission
     passband having a wavelength (λ) given by

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$$\lambda = 4nt$$

wherein n is the value of either the H
or the L refractive index of the layers,
and

10

wherein t is the total thickness of the
layer of corresponding refractive index
at a given point along said dispersing
means from a reference point.

1   4.   A spectrometer as defined in Claim 3
wherein said layers HH of said given sequence are a
spacer layer having a thickness substantially equal to
a length associated with a number of·whole wavelengths.

1   5.   A spectrometer as defined in Claim 4
further comprising at least one interference blocking
stack interposed between said incident radiation beam
and an upper one of said layers.

1   6.   A spectrometer as defined in Claim 4
wherein said detecting means comprises a two
dimensional array of photodiodes disposed to detect
said dispersed radiation beam at a plurality of points.

1   7.   A wedge-filter spectrometer comprising:

a substrate comprised of a material
which is substantially transparent to a
cone of radiation incident upon a first
5   surface of said substrate,

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a plurality of linearly tapered interference layers disposed upon a second opposite surface of said substrate, said layers being disposed one upon another in a stacked fashion, each of said layers having a widest thickness along a first edge of said substrate and a narrowest thickness disposed along a second, opposite edge of said substrate, certain ones of said plurality of layers being comprised of a material having a high (H) index of refraction and certain ones of said plurality of layers being comprised of a material having a low (L) index of refraction, said H and L layers being arranged one upon another in accordance with a predetermined sequence for spectrally dispersing the incident radiation;

a two dimensional array of radiation detectors being disposed substantially parallel to said first surface of said substrate and underlying said plurality of layers, said array being responsive to said spectrally dispersed radiation at a plurality of points therein; and

means for maintaining said array of detectors in a parallel orientation with said upper surface.

20

1   8.   A spectrometer as defined in Claim 7
wherein said predetermined sequence .defines a resonant
cavity structure for producing a wavelength passband
centered at a wavelength of λ_c where

5   λ_c is the passband center wavelength, and

                 λ_0 is a reference wavelength given by

             $\lambda_0 = 4n_H t_H = 4n_L t_L$

             wherein

             n_H is the index of refraction of said H
10   material,

             t_H is the thickness of said H material,

             n_L is the index of refraction of said L
             material, and

             t_L is the thickness of said L material.

1   9.   A spectrometer as defined in Claim 8
wherein said predetermined format is defined by layers

                     H LL HLHLHL HH LHLHLH LL HL

and wherein the layers HH define a spacer layer the
5   thickness of which is determinative of a width of said
passband in accordance with the number of wavelengths

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Λ_c that evenly fit within the thickness of said spacer
layer.

1   10. A spectrometer as defined in Claim 9
wherein said plurality of interference layers comprise
a plurality of said resonant cavity structures disposed
one upon another for decreasing the width of said
5   passband.

1   11. A spectrometer as defined in Claim 10
wherein said spectrometer is responsive to radiation
within a range of wavelengths of approximately 400 nm
to 1000 nm and wherein said spectrometer further
5   comprises a plurality of interference blocking stacks
disposed upon said first surface of said substrate,
each of said stacks being responsive to a given range
of wavelengths for rejecting said given range of
wavelengths.

1   12. A spectrometer as defined in Claim 11
wherein said plurality of interference blocking stacks
comprise three interference blocking stacks disposed
adjacent one another upon said first surface, said
5   stacks being disposed from said first edge to said
second edge.

1   13. A spectrometer as defined in Claim 12
wherein

                          a first one of said stacks is comprised
                          of a plurality of substantially constant
5   thickness layers of H and L material
                          given by

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$[LH]^6 1.3 [LH]^6$, where L and H are quarter waves at approximately λ = 520 nm;

a second one of said stacks is comprised of linearly tapered layers of H and L material given by

$[LH]^7 2 [LH]^7$, where L and H are quarter waves at approximately λ = 420 nm; and

a third one of said stacks is comprised of substantially constant thickness layers of H and L material given by

$[LH]^6 1.6 [LH]^6$, where L and H are quarter waves at approximately λ = 250 nm.

14. A spectrometer as defined in Claim 7 where said substrate is comprised of optical glass and wherein said L material is comprised of silicon dioxide and wherein said H material is comprised of titanium dioxide.

15. A spectrometer as defined in Claim 7 wherein said maintaining means is a tapered layer of optical cement.

16. A spectrometer as defined in Claim 13 wherein said cone of radiation is incident upon said first surface at an angle of between approximately 10° to 20° from a normal to said said first surface.

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1   17. A method of depositing a layer of
material upon a first surface of a substrate such that
the layer has a predetermined linearly tapered
thickness along a given axis of the substrate and a

5   substantially constant slope, comprising the steps of:

providing a substantially transparent
substrate upon a substrate mount;

translating the substrate mount in an
oscillatory linear manner along an axis

10   coincident with the given axis;

directing a flow of material to the
first surface of the substrate in a
direction normal to the given axis, the
flow depositing a layer of the material

15   upon the first surface;

positioning an aperture within the flow
such that the aperture selectively
blocks the flow from reaching the first
surface of the substrate as the

20   substrate is translated past an edge of
the aperture and behind the aperture,
the substrate thereby being translated
into and out of the flow such that a
linearly tapered thickness of material

25   is deposited on the first surface;

passing a first and a second beam of
radiation through a back surface of the
substrate at a first and a second

24

predetermined point, respectively,
relative to a reference point;

detecting the magnitude of the intensity
of the first and second beams of
radiation after they have passed through
the substrate and through the layer; and
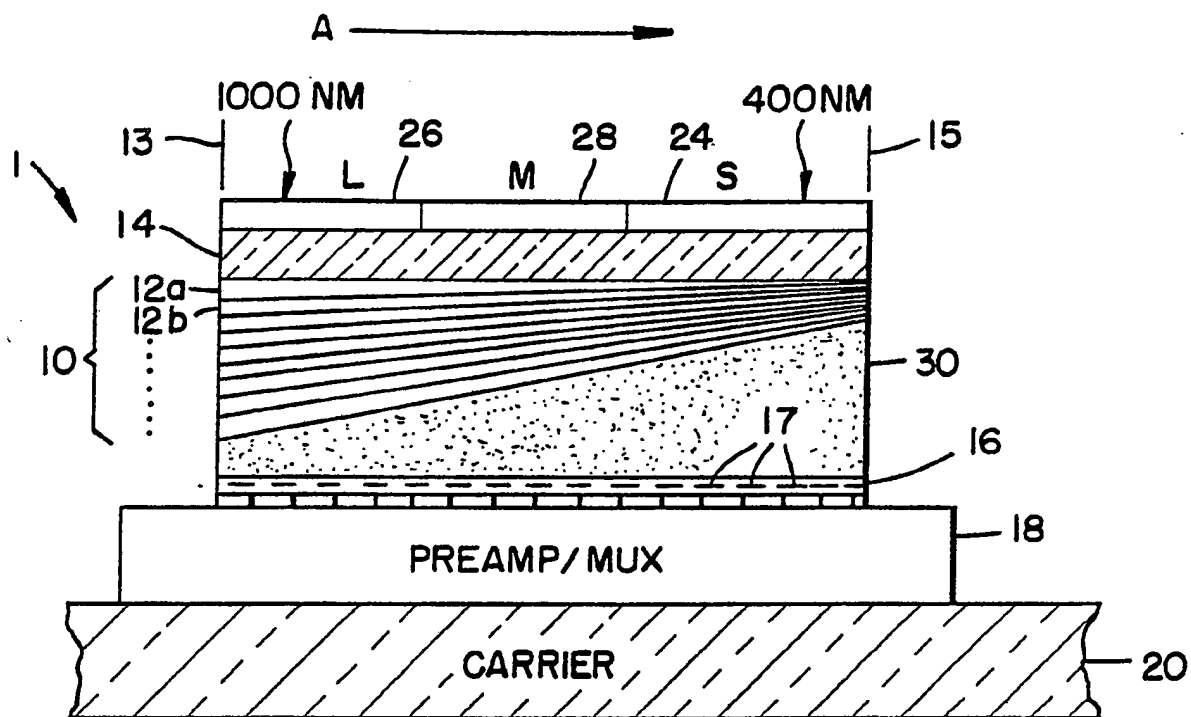
comparing the detected intensity of each
of the beams to a reference intensity to
determine a difference therebetween, the
difference of each of the intensities
from the reference intensity being
indicative of a thickness of the layer
at the first and the second
predetermined points.

18. The method of Claim 17 further
comprising a step of comparing the detected intensity
of the first beam to that of the second beam to
determine a difference therebetween, the difference
being indicative of the slope of the taper thickness
between the first and the second points.

19. Apparatus for depositing a layer of
material upon a first surface of a substrate such that
the layer has a predetermined linearly tapered
thickness along a given axis of the substrate and a
substantially constant slope, comprising:

means for mounting a substantially
transparent substrate;

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means for translating said mounting
means in an oscillatory linear manner
along an axis coincident with the given
axis;

means for directing a flow of material
to the first surface of said substrate
in a direction normal to said given
axis, the flow depositing a layer of the
material upon said first surface;

means for positioning an aperture within
the flow such that said aperture
selectively blocks the flow from
reaching said first surface of said
substrate as the substrate is translated
past an edge of said aperture and behind
said aperture, said substrate thereby
being translated into and out of the
flow such that a linearly tapered
thickness of material is deposited on
said first surface;

means for passing a first and a second
beam of radiation through a back surface
of the substrate at a first and a second
predetermined point, respectively,
relative to a reference point;

means for detecting the magnitude of the
intensity of said first and said second
beams of radiation after they have

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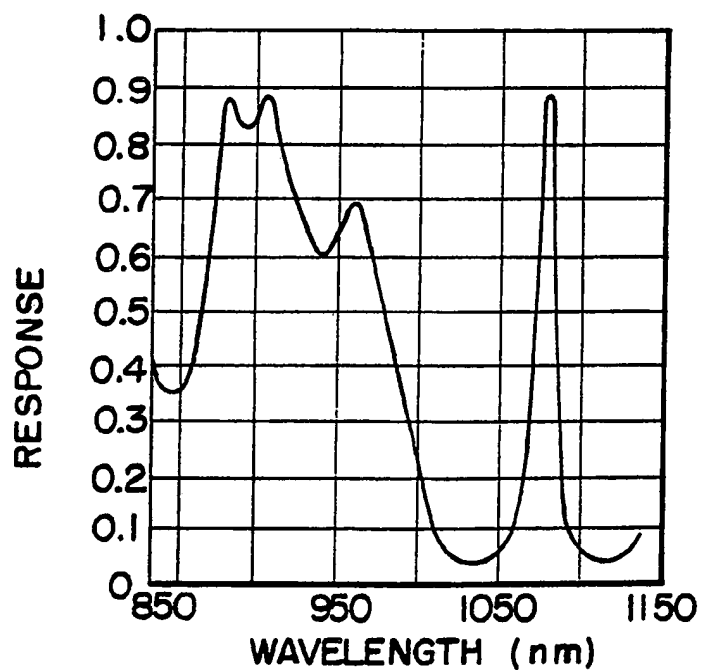passed through said substrate and
through said layer deposited thereon;

means for comparing said detected
intensity magnitude of each of said
40   beams to a reference intensity to
determine a difference therebetween, the
difference of each of said intensities
from the reference intensity being
indicative of a thickness of said layer
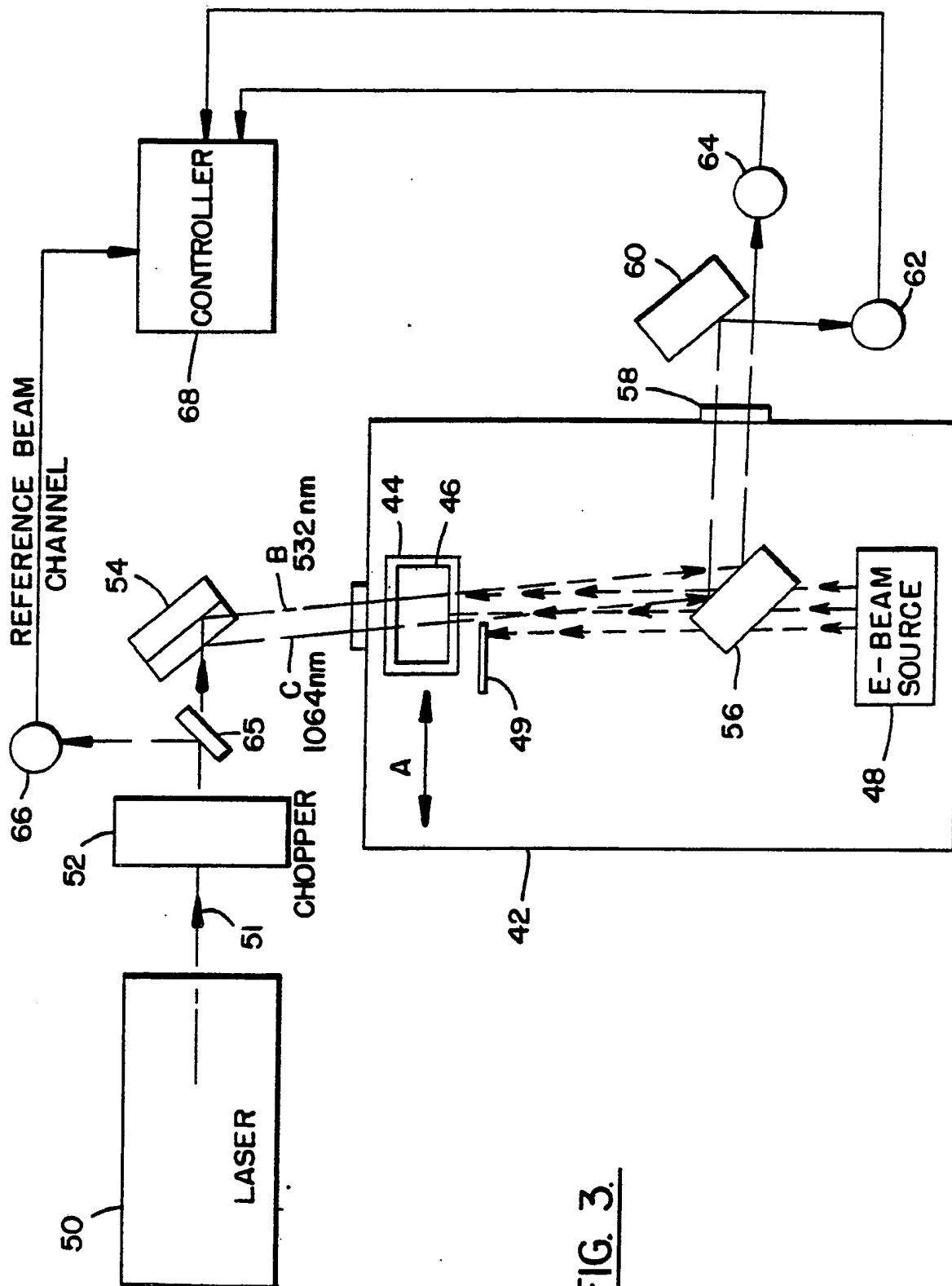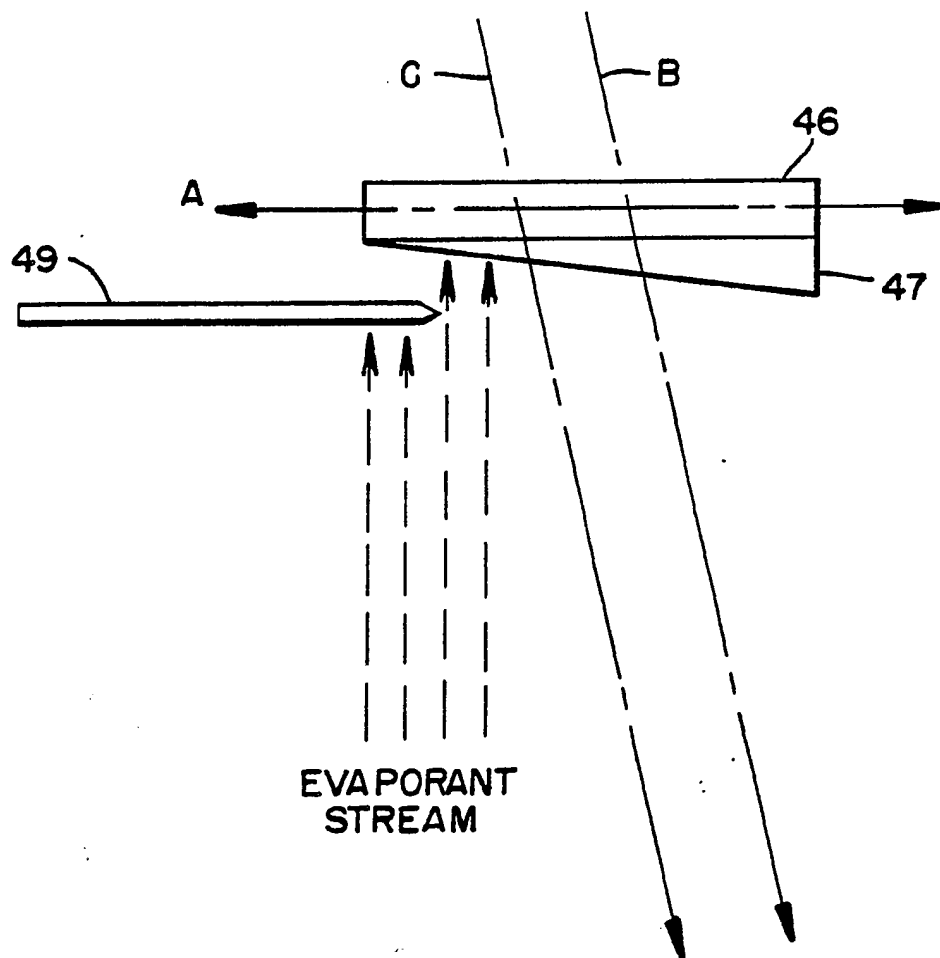45   at said first and said second
predetermined points.

1   20. The apparatus of Claim 19 further
comprising means for comparing said detected intensity
of said first beam to that of said second beam for
determining a difference therebetween, the difference
5   being indicative of the slope of the taper thickness
between said first and said second points.

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FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

EVAPORANT
STREAM

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 88/03898

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC4: G 02 B 5/28, G 01 J 3/36

II. FIELDS SEARCHED

Minimum Documentation Searched *

Classification System *	Classification Symbols
IPC4	G 01 J, G 01 N, G 02 B

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched *

III. DOCUMENTS CONSIDERED TO BE RELEVANT *

Category *	Citation of Document, ** with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
Y	US, A, 4054389 (JEN) 18 October 1977, see figures 1,2	1,7
A		6
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Y	US, A, 3442572 (R.F. ILLSLEY ET AL) 6 May 1969, see claims 1,2,4	1,7
A		2-4,8-16
	--	
A	US, A, 4346992 (SCHWARTZ) 31 August 1982, see the whole document	1-16
	--	
A	US, A, 3929398 (BATES) 30 December 1975, see the whole document	1-16
	--	

* Special categories of cited documents: 10

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
14th March 1989	3 0 MAR 1989

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	M. VAN MOL

Form PCT/ISA/210 (second sheet) (January 1985)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	Patent Abstracts of Japan, Vol 7, No 26, P172, abstract of JP 57-179807, publ 1982-11-05 CANON K.K. --	1-16
A	US, A, 2708389 (F.W. KAVANAGH) 17 May 1955, see claims 1-4 --	5,11, 12
A	Derwent's abstract, No. 86 231 694/35, SU 748 747, publ. week 8635 --	14,17-20
A	DE, A1, 3026370 (AGA AB) 15 January 1981, see page 10. line 2 - line 7 --	17-20
A	Patent Abstracts of Japan, Vol 10, No 143, P459, abstract of JP 60-262102, publ 1985-12-25 HORIBA SEISAKUSHO K.K. --	17-20
A	Patent Abstracts of Japan, Vol 10, No 127, P455, abstract of JP 60-252304, publ 1985-12-13 HITACHI SEISAKUSHO K.K. --	17-20

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The members are as contained in the European Patent Office EDP file on   12/01/89
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		DE-A-C- 2739585	30/03/78
		GB-A- 1542347	14/03/79
		JP-A- 53039784	11/04/78
		CA-A- 1082485	29/07/80
US-A- 3442572	06/05/69	US-A- 3530824	29/09/70
		DE-A-B,C 1472196	19/09/74
US-A- 4346992	31/08/82	NONE	
US-A- 3929398	30/12/75	NONE	
US-A- 2708389	17/05/55	NONE	
DE-A1- 3026370	15/01/81	GB-A- 2054195	11/02/81
		JP-A- 56035109	07/04/81